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A HOT-HARDNESS SURVEY OF THE ZIRCONIUM–URANIUM SYSTEM

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May 28, 1953

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ATOMIC ENERGY COMMISSION ★ UNITED STATES OF AMERICA ★

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ABSTRACT

A complete hardness survey of the zirconium-uranium system has been made at temperatures from room temperature to 900 C. The composition of maximum hardness increases from 40 at. % zirconium at room temperature to 60 at. % zirconium at 600 C. At 700 C, the hardness data indicated the presence of the beta uranium phase in alloys containing 95 and 100 at. % uranium. This phase was found to be unusually hard. At 900 C, maximum hardness of the gamma zirconium-uranium solid solution was found to occur at about 50 at. %.

May 28, 1953

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INTRODUCTION

As the interest in zirconium-uranium alloys increases, the need for mechanical-property data increases. An evaluation of the effect of uranium on the strength of alloys at elevated temperatures becomes highly desirable as a guide for design and fabrication. Such data are most readily obtained by means of hardness measurements. While hardness measurements are necessarily relative and cannot be interpreted in terms of ductility, they are quite adequate as a measure of relative strength. The ease with which a complete hardness survey of an alloy system can be made gives hardness measurements an advantage over other methods of mechanical-property measurement.

APPARATUS

Hardnesses at elevated temperatures were determined in apparatus designed to handle easily oxidized metals in a vacuum at temperatures up to 1000 C. A diagram showing the essential features of the machine appears in Figure 1. The diagram shows an elevation view of a cross section of the machine. The vacuum and accessory port is on the extreme left; the specimen-positioner-rod assembly is on the right; a dead-weight loading system occupies the upper half; and the movable pedestal is shown in the lower center. The center of the drawing shows an annular, wire-wound resistance furnace and surrounding radiation shields. The outer walls are water cooled and vacuum tight. Rubber O-rings and gaskets at each joint allow the machine to be opened for repairs or to change specimens.

All parts of the machine exposed to elevated temperatures are made of stainless steel or ceramic; the remainder are made of brass or other conventional materials. The pedestal is ceramic and contains the control thermocouple. It is rigidly supported by a stainless steel block, a stainless steel bellows, and a heavy steel screw. Furnace temperature is maintained by a voltage control system regulated by the control thermocouple. The sapphire-tipped indenter is heated to essentially the same temperature as the specimen. The sapphire has a Vickers pyramid tip.

In operation, the chamber is evacuated to an absolute pressure of less than 5 microns of mercury, and the specimen resting on the pedestal is heated to some temperature as determined by the control thermocouple. The specimen is moved into place under the indenter column by means of the positioner rod, which is then retracted from the furnace. The pedestal is raised until the specimen contacts the indenter and raises the indenter

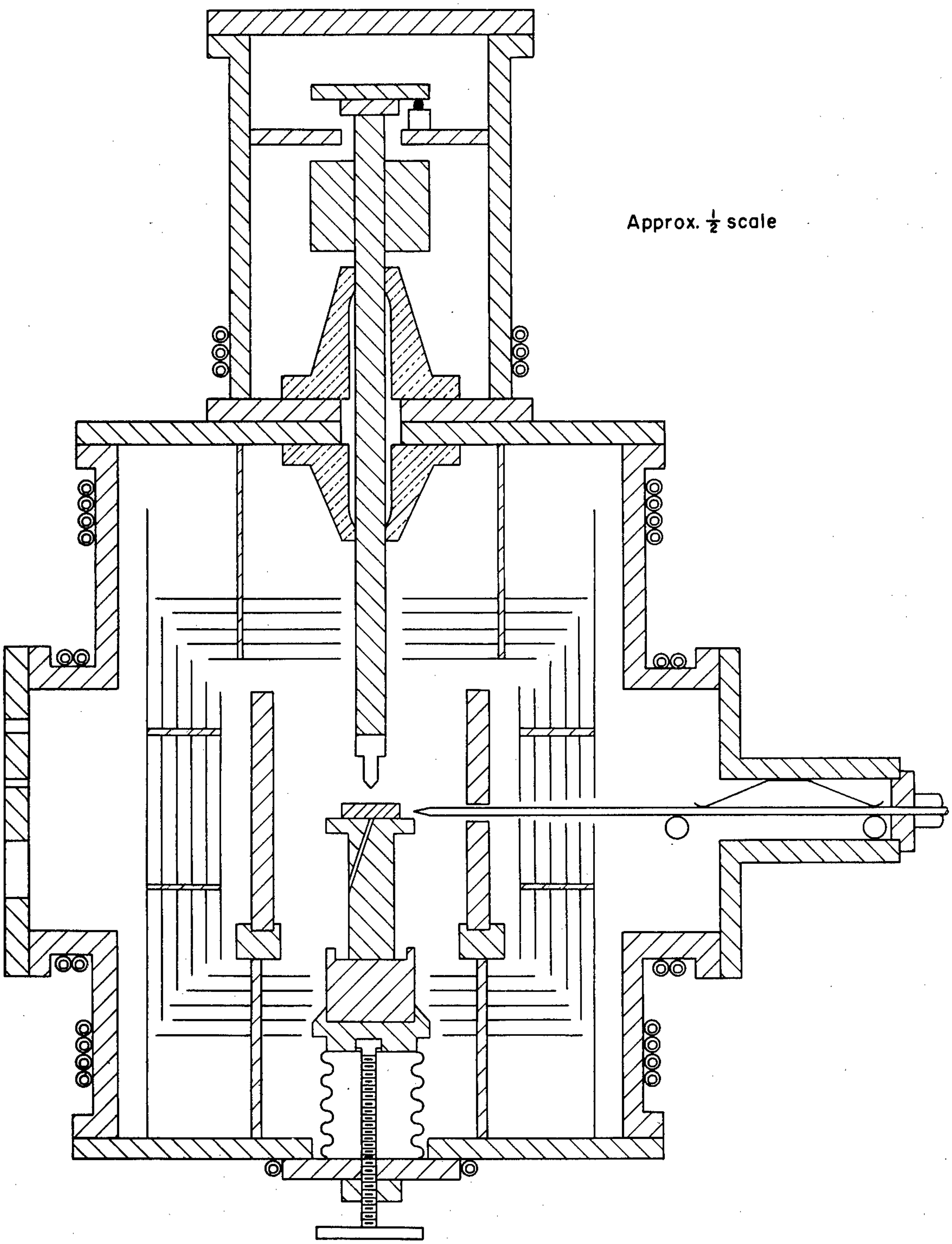

FIGURE 1. VACUUM HOT-HARDNESS MACHINE

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column off a microswitch. The indenter column, which weighs approximately 1 kilogram, is allowed to remain in contact with the specimen for approximately 10 sec. The pedestal is then lowered and the process is repeated. Friction between the stainless steel indenter column and the brass guides is equivalent to less than 10 g.

MATERIALS

The zirconium used in preparing the alloys mentioned in this report was Foote Mineral Company, Grade 1, iodide zirconium. Some alloys were prepared with "Derby" uranium; others were prepared with "Fernald" uranium. Some alloys were prepared by arc melting; others were prepared by induction melting.

All alloys were reduced to 1/8-in. sheet by rolling in the gamma range at temperatures between 700 C and 930 C. Prior to testing, all alloys were heated for 24 hr at 575 C.

RESULTS OF EXPERIMENT

The results of the hardness tests are shown in Table 1. The results for each composition and selected temperatures have been averaged and plotted as Figure 2. Isotherms are shown for hardnesses at room temperature, 300 C, 500 C, 600 C, 700 C, 800 C, and 900 C. Appropriate phase relationships have been indicated for certain curves.

The room-temperature curve shows a maximum hardness at approximately 60 at. % (80 wt %) uranium. As the temperature is increased, this peak shows a tendency to shift to a lower percentage uranium alloy. It is also interesting to note that the hardness of the pure metals falls off much more rapidly with increasing temperature than does the hardness of the intermediate alloys.

The curve at 600 C is complicated by the appearance of the gamma phase in the zirconium-rich alloys. This also occurs in a temperature range where the hardness of all zirconium-uranium alloys changes very rapidly with changes in temperature. The result is a series of erratic points.

The curve at 700 C shows the effect of the occurrence of the hard and intractable beta-uranium structure. The curves at 700, 800, and 900 C show the effect of the gradual appearance of the gamma phase at the expense of the low temperature structures with increasing temperature. At 650 C, the hardest and most stable gamma alloy occurs at approximately 35 at. %

TABLE 1. HARDNESS OF ZIRCONIUM-URANIUM ALLOYS

Nominal Alloy Composition		Hardness (VPHN), kg/mm², at Temperature, C										Type of Uranium and
At. % U (Balance Zr)	Wt % U (Balance Zr)	Room	300	500	600	650	700	750	800	850	900	Melting Method(a)
0	0	113	53	33	22	--	16.6	12.5	9.3	7.2	1.4	D-A
0	0	138	58	39	27	--	14.5	11.1	8.7	8.4	2.6	F-I
4	10	246	195	85	32	--	9.8	6.1	4.4	4.2	2.8	D-A
4	10	197	141	108	51	--	25	16.4	8.2	2.9	2.0	F-I
8.5	20	235	182	102	24	--	6.4	--	3.6	2.7	2.1	D-A
8.5	20	252	188	136	56	--	16	7.3	5.0	4.2	3.7	F-I
14	30	243	185	136	28	--	10.5	7.3	4.3	3.2	—	D-A
14	30	298	249	168	75	--	10	7.4	5.7	4.8	4.1	F-I
20	40	295	255	172	70	--	9.7	6.8	5.4	4.1	3.6	D-A
20	40	271	227	178	96	13.7	10.0	6.3	5.4	--	3.6	D-I
20	40	302	264	194	100	15.7	11.9	8.2	7.0	--	4.9	F-I
27	50	272	242	183	92	--	10.9	8.5	6.9	5.9	4.5	D-A
27	50	264	262	192	101	18.7	12.8	10.4	8.6	--	5.9	F-I
36	60	279	231	211	96	--	15.7	12	9.9	7.6	7.1	D-A
36	60	364	337	249	81	17.1	18.0	15.2	11.5	--	7.3	D-I
36	60	242	247	224	104	23	16.9	12.5	9.5	--	6.3	F-A
48	70	350	293	219	75	--	19.0	15	12.5	10.8	8.5	D-A
48	70	370	320	245	73	15.4	10.5	14.9	13.7	--	8.4	F-I
60	80	411	341	212	57	--	12.8	18.1	13.6	11.2	8.9	D-A
60	80	391	341	209	90	26	13.1	14.8	15.7	--	8.8	F-I
60	80	386	335	213	77	22	10.3	10.6	11.9	--	8.4	F-A
60	80	421	354	209	80	25	7.6	15.0	12.1	--	7.3	D-I
77	90	359	258	129	26	--	4.6	10.6	8.6	--	5.9	D-A
77	90	363	258	159	68	--	14.0	9.6	7.1	5.2	2.2	F-I
88	95	307	181	106	49	22	7.6	5.4	4.4	--	3.0	D-A
88	95	347	139	118	38	--	6.4	4.7	3.6	2.7	2.3	F-I

TABLE 1. (Continued)

Nominal Alloy Composition		Hardness (VPHN), kg/mm^2, at Temperature, C											Type of Uranium and
At % U (Balance Zr)	Wt % U (Balance Zr)	Room	300	500	600	650	700	750	800	850	900	Melting Method[a]
95	98	283	155	85	49	35	39	2.3	2.0	--	1.7	D-A
100	100	249	91	29	14.5	--	33	--	--	--	--	D-A
100	100	263	144	49	23	17.5	43	28	1.7	--	0.6	D-A
100	100	200	68	23	13	--	31	--	--	--	--	F-I
100	100	265	117	37	18.7	12.7	33	23	0.79	--	0.72	F-I

(a) D = Derby uranium A = Arc-melted alloy
F = Fernald uranium I = Induction-melted alloy

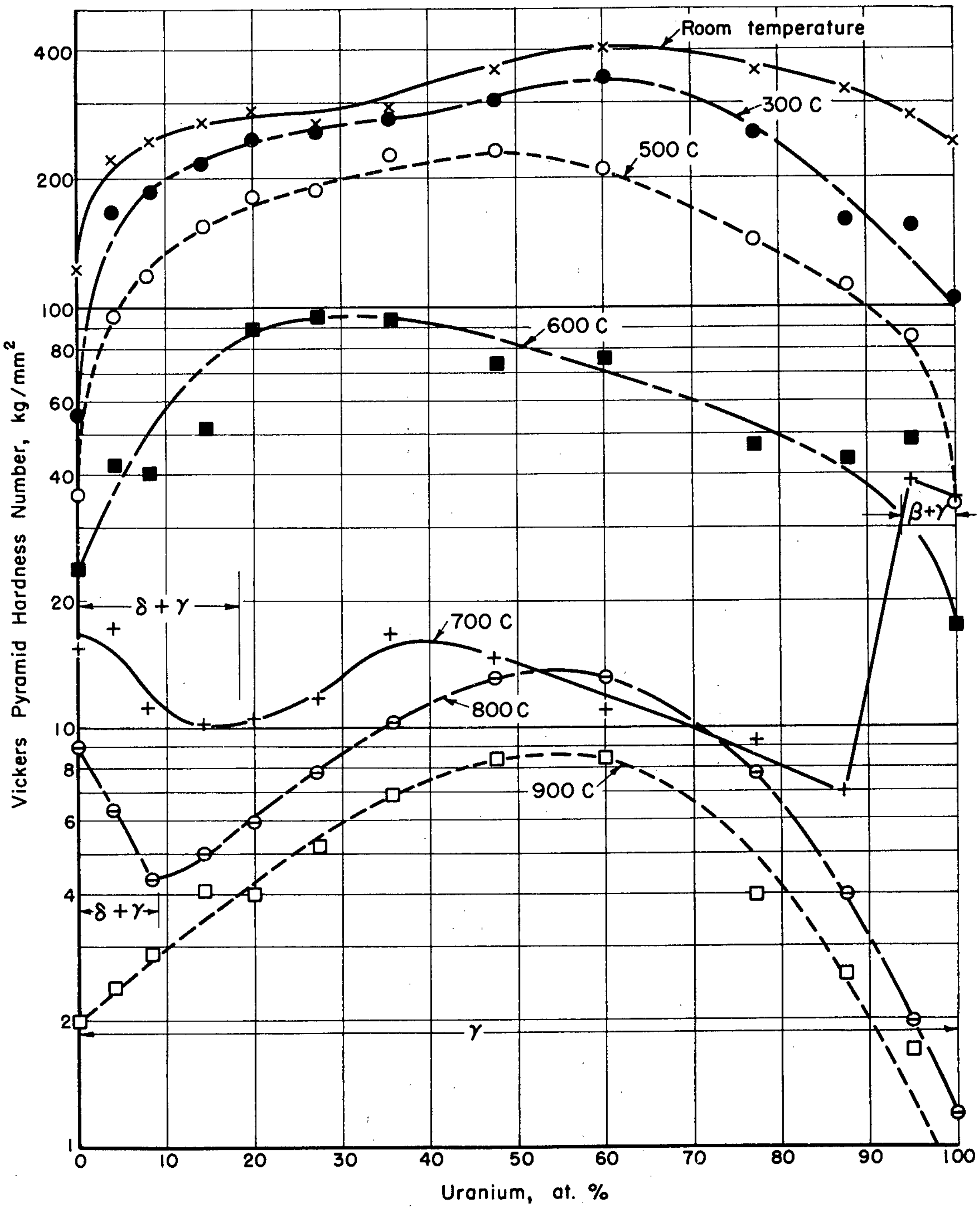

FIGURE 2. HARDNESS ISOTHERMS IN THE ZIRCONIUM—URANIUM SYSTEM

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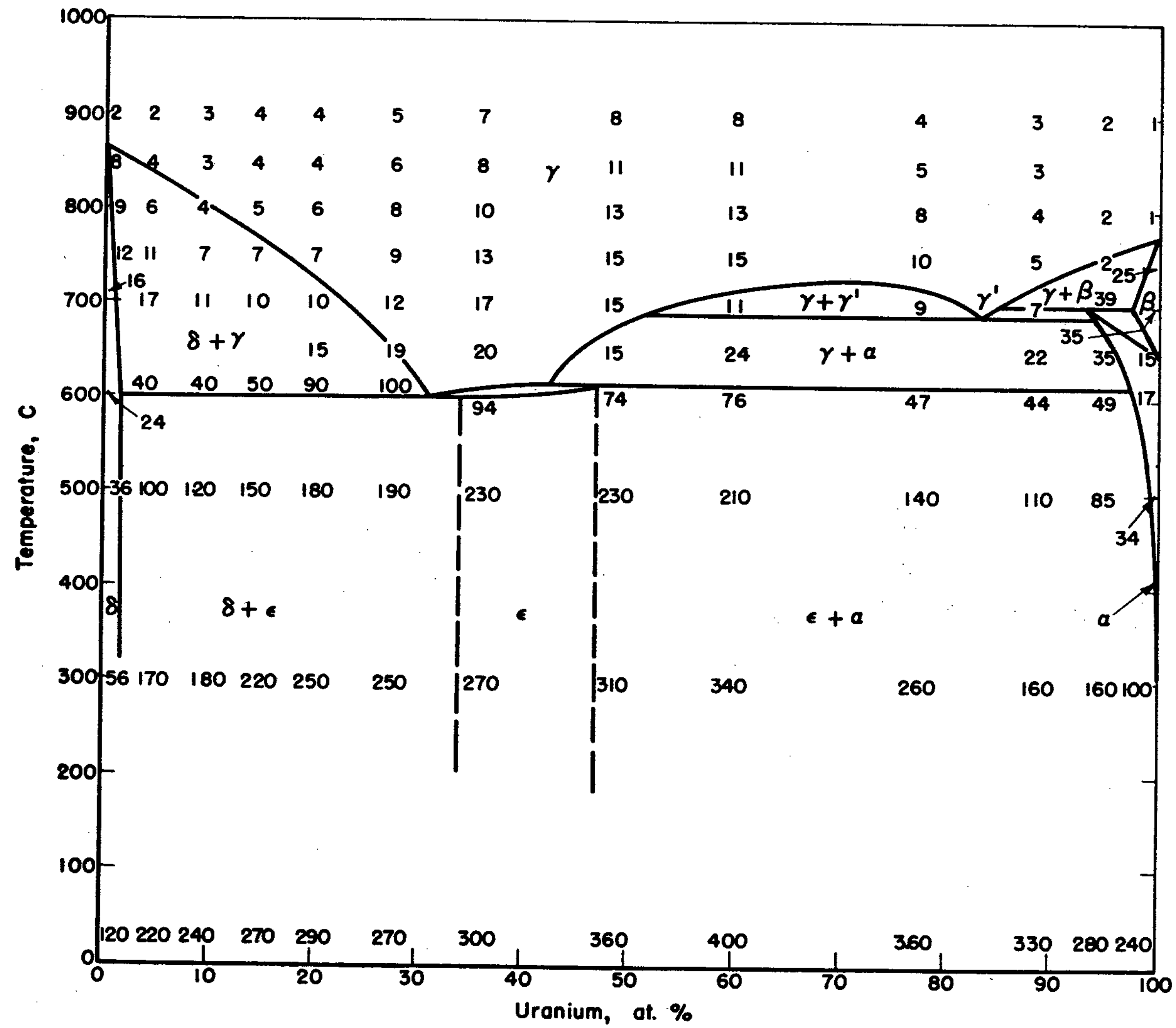

FIGURE 3. HARDNESS–TEMPERATURE RELATIONSHIPS IN THE ZIRCONIUM–URANIUM SYSTEM
Hardness in VPHN

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(60 wt %) uranium. At higher temperatures, this peak shows a tendency to shift to a higher percentage uranium alloy.

Figure 3 shows part of the uranium-zirconium phase diagram prepared by H. A. Saller, F. A. Rough, and A. A. Bauer and reported in BMI-803, December, 1952. Superimposed upon this diagram are averages of the hardness values shown in Table 1. It is interesting to note that the $\gamma + \gamma'$ - phase field shows lower hardness than γ of the same composition at a higher temperature. Between 650 C and 760 C, the beta-uranium structure is by far the hardest of all zirconium-uranium alloys. Alloys containing beta uranium undoubtedly are more difficult to roll than other compositions in this system.

CONCLUSIONS

1. A hardness survey of the zirconium-uranium system shows a maximum hardness at room temperature at about 60 at. % (80 wt %) uranium. With increasing temperatures up to 600 C, this maximum tends to shift toward 36 at. % (60 wt %) uranium. Between 500 C and 600 C this maximum corresponds to the approximate location of the eta phase field.

2. The beta uranium phase is much harder than any other zirconium-uranium alloy in the temperature range from 650 C to 760 C.

3. Maximum hardness of the gamma zirconium-uranium solid solution at 650 C occurs at about 36 at. % (60 wt %) uranium. With increasing temperature up to 900 C, this maximum tends to shift toward 50 at. % (75 wt %) uranium.